

Case No.: EDROE-010A

## STEEL ALLOY FOR INJECTION MOLDS

### CROSS-REFERENCE TO RELATED APPLICATIONS

**[0001]** The present application claims priority to U.S. Provisional Application Serial No. 60/509,953 entitled P1 ALLOY filed October 9, 2003.

### STATEMENT RE: FEDERALLY SPONSORED RESEARCH/DEVELOPMENT

**[0002]** (Not Applicable)

### BACKGROUND

**[0003]** This invention relates to a steel alloy and, more particularly, to a tool steel alloy having good machinability and dimensional stability and being specifically designed and optimized for use in plastic mold tooling.

**[0004]** Tooling for plastic injection molds has evolved with increasing sophistication as the uses of and demands upon plastics have grown. Such tooling may include hot runner manifolds that may be fabricated of steel alloy. However, known alloy steels that are currently used for such tooling applications suffer from several deficiencies that detract from their overall utility. For example, alloy steels currently used for plastic injection mold tooling may have unfavorable ductility characteristics such that the tooling may fracture under relatively low deformation loads.

**[0005]** In addition, such alloy steel may possess poor weldability characteristics making fabrication and repair of the tooling difficult. Furthermore, currently known alloy steels

used in plastic injection mold tooling may suffer from poor dimensional stability manifested by high levels of waviness and wrinkling in the material in addition to warping of the material at elevated temperatures. Other deficiencies of currently known alloy steel used for injection mold tooling are low strength and low hardness properties.

**[0006]** In an attempt to overcome the above-mentioned deficiencies associated with such alloy steels, manufacturers have traditionally employed several refining processes in order to reduce impurities in the alloy steel so that relatively uniform mechanical properties may be achieved over an entire cross section of the tooling. Such refining processes may include electro-slag remelting (ESR) and vacuum arc remelting (VAR). Alloy steels produced using ESR and VAR processes may be less susceptible to the introduction of impurities during pouring of the melted steel as compared to air melt poured steel.

**[0007]** In addition, ESR and VAR practices may result in a high level of cleanliness and a generally homogenous microstructure of the alloy steel. Unfortunately, ESR and VAR refining is associated with an excessively high overall cost in the production of the alloy steel. Furthermore, the production of alloy steel using ESR and VAR refining may entail even further costs when the chemical composition by percent weight of the alloy steel is restricted to within a relatively narrow range. Such a narrow range of key elements may be required for alloy steel intended for use in injection mold tooling.

**[0008]** As can be seen, there exists a need in the art for an alloy steel that has improved ductility, weldability and dimensional stability such that the alloy steel may be used in injection mold tooling. In addition, there exists a need for an alloy steel that is producible at high cleanliness levels and

that has sufficiently high strength and hardness properties suitable for use in injection mold tooling. There also exists a need in the art for alloy steel that may be produced with a high level of flatness and with minimal bending stresses that may be otherwise induced into the material during cooling of the material. Finally, there exists a need in the art for an alloy steel that may be produced in a manner that is favorable from a cost point of view.

#### BRIEF SUMMARY

[0009] Provided is a steel alloy as may be used in tooling in the plastic injection molding industry. The steel alloy has a specific chemical composition that is uniquely adapted to meet requirements for strength, ductility, weldability and dimensional stability as may be required for a manifold used in plastic injection molding. Also provided is a process for manufacture of the steel alloy. The steel alloy is electric furnace melted, ladle refined, vacuum degassed and argon shield poured in order to provide a product that is naturally flat and that is free of bending stresses and heavy scale.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0010] Figure 1 is an illustration of plastic injection tooling including a manifold that may be formed of a steel alloy.

#### DETAILED DESCRIPTION

[0011] Provided is a steel alloy and process for manufacture thereof. Also provided is a manufacturing mold having a portion thereof including a manifold 16 that may be formed of the steel alloy. As can be seen in Fig. 1, the manifold 16 may include

sprues 18 or runners 20 such that the manifold 16 may be used in plastic injection mold 10. The steel alloy has a chemical composition as shown in Table I. The steel alloy is electric furnace melted, ladle refined, vacuum degassed and argon shield poured in a manner as will be described in greater detail below. The composition range of the elements of the tool steel alloy is given in ranges of percent weight in Table I below. The values are preferred, and variations in one or more elements are permissible which do not alter the suitability of the alloy for use in plastic injection molds.

TABLE I

<u>Composition of Steel Alloy</u>										
Element	C	Mn	P	S	Si	Cr	Ni	Cu	Mo	Al
Minimum	.16	.6	0	0	.25	2.3	0	0	0	.015
Maximum	.20	.9	.02	.02	.45	2.7	.2	.15	.1	.03
Typical	.18	.75	.01	.01	.35	2.5	.1	.07	.05	.023

**[0012]** The balance of the composition is iron (Fe) and those impurities and tramp or trace elements that are inevitably included during the melting of a material charge from which the steel alloy may be ultimately produced. Preferably, any additional element in an amount which does not alter the suitability of the alloy for use in plastic injection molds may be considered either an impurity or trace element. The function of each of the intentionally included elements in the composition is as follows:

**[0013]** Carbon (C): about .16 to .2%

[0014] Carbon controls the degree of hardness and tensile strength that is attainable in the steel alloy. However, ductility and weldability decrease with increasing levels of carbon. Therefore, the carbon level of the steel alloy advantageously ranges from about .16 to about .2%, preferably from about .17-.19%, and in particular about .18% by weight. With such composition ranges, the desired hardness of the alloy may range from about 277 to about 311 Brinell Hardness Number (BHN) after tempering.

[0015] Manganese (Mn): about .6 to .9%

[0016] Manganese acts as a strengthening agent and as a de-oxidizer. In addition, manganese acts as an austenite stabilizer and prevents the formation of ferrite phase in the steel alloy. Furthermore, manganese is generally beneficial to surface quality of parts made of the steel alloy. The upper limit of .9% manganese is specified to control otherwise embrittling effects of excess manganese. The manganese level of the steel alloy advantageously ranges from about .6 to about .9%, preferably from about .7-.8%, and in particular about .75% by weight. The specified range of .6-.9% manganese produces all the desired effects with no negative impact on mechanical properties of the steel alloy.

[0017] Phosphorus (P): up to a maximum of about .02%

[0018] Phosphorous adds to the strength and hardenability of the steel alloy. However, the phosphorous in the steel alloy is typically reduced to the lowest level possible to avoid brittleness in the steel alloy. For this application, the phosphorus is intentionally not reduced to extremely low levels. An upper limit of about .02% phosphorous was specified to take advantage of phosphorus' slight contribution to corrosion resistance in the steel alloy. More importantly, however, the upper limit of phosphorous was specified for its positive

affects on machinability. The level of phosphorous may preferably be specified at about .01% as a balance between its enhancement of machinability and its inducement of brittleness in the steel alloy.

**[0019]** Sulfur (S): up to a maximum of about .02%

**[0020]** Sulfur is generally a non-desirable element in most steels. Sulfur is a remnant of fuels used to manufacture iron and steel. Weldability typically decreases with increasing sulfur content. For these reasons, sulfur at the specified upper limit of .02% is effective in producing the steel alloy with a relatively high level of weldability. At the same time, the level of sulfur in the steel alloy remains in balance with the rest of the elements in the composition to the extent that hot working properties, toughness, ductility and corrosion resistance remain acceptable. Toward this end, the maximum level of sulfur in the steel alloy may preferably be specified at about .01%

**[0021]** Silicon (Si): about .25 to .45%

**[0022]** Silicon acts as a primary de-oxidizer in the metal although silicon is less effective than manganese in increasing strength and hardness. Deoxidizing action occurs with silicon present in the composition of the steel alloy. However, increasing levels of silicon may produce ferrite. Therefore, the silicon level of the steel alloy advantageously ranges from about .25 to about .45%, preferably from about .3-.4%, and in particular about .35% by weight.

**[0023]** Chromium (Cr): about 2.3 to 2.7%

**[0024]** Chromium acts to enhance hardenability and high-temperature strength in the steel alloy making possible a material that will readily transform to the desired material structure in relatively thick cross sections with air cooling. Chromium content of 2.3% minimum is provided to give sufficient

corrosion resistance and oxidation resistance in the steel alloy. Increasing levels of chromium may promote the formation of the undesirable ferrite phase in the steel alloy. Therefore, the chromium level of the steel alloy advantageously ranges from about 2.3 to about 2.7%, preferably from about 2.4-2.6%, and in particular about 2.5% by weight.

**[0025]** Nickel (Ni): up to a maximum of about .15%

**[0026]** Nickel is a ferrite strengthener in the steel alloy. Nickel also slightly improves the corrosion resistance of the steel alloy, particularly for the plastic injection mold 10 application for which the steel alloy is intended. Such resistance in the steel alloy is desirable in order to mitigate deleterious effects of reducing chemicals contained in plastic. In addition, the nickel may counteract negative effects of hot working that the copper may create. Nickel also increases the hardenability and impact strength of the steel alloy. Therefore, an upper limit of .15% of copper has been specified. However, the level of nickel may preferably be specified at about .075% in order to limit negative effects of the nickel on overall machinability.

**[0027]** Copper (Cu): up to a maximum of about .15%

**[0028]** Like sulfur, copper is generally a non-desirable element in most steels. Copper is typically a remnant of fuels used to manufacture iron and steel. More specifically, copper is present as a result of contamination of scrap metal that is used to manufacture the steel alloy. High levels of copper can promote hot working problems and can be detrimental to surface quality. Therefore, copper is specified at the upper limit of .15%. The level of copper in the steel alloy may preferably be specified at about .075% in order to improve the mechanical properties for the steel alloy.

**[0029]** Molybdenum (Mo): up to a maximum of about .1%

**[0030]** Molybdenum is added at an upper limit of about .1% in order to provide sufficient resistance to cracking in the steel alloy such as may occur during hot leveling of the steel alloy material. In addition, molybdenum improves corrosion resistance in the steel alloy and improves creep strength of the steel alloy at elevated temperatures. The level of molybdenum may preferably be specified at about .05% in order to maintain a balance with the rest of the elements in the composition to the extent that hot working properties and corrosion resistance remain acceptable.

**[0031]** Aluminum (Al): about 0.015 to 0.03%

**[0032]** Aluminum may work in concert with silicon to act as a de-oxidizer. In addition, aluminum is one of the most effective elements in inhibiting grain growth in the steel alloy. In this regard, the aluminum is included to provide a relatively fine grain structure in the finished material. Therefore, the aluminum level of the steel alloy advantageously ranges from about .015 to about .03% and preferably about .02% by weight.

#### DETAILS OF MANUFACTURING

**[0033]** A tool such as a manifold 16 for plastic injection molding may be formed from the steel alloy in a process that is initiated with preparation of a material charge. The material charge may be prepared using the elements listed above and in the ranges specified for the chemical composition. The material charge may include additional amounts of certain elements to account for estimated melt losses as a result of oxidation during the production of the tool steel.

**[0034]** Following its preparation, the material charge is introduced into an electric furnace such as a conventional electric furnace of the type used in manufacturing ferrous and non-ferrous metals. Melting of the material charge may be



achieved by supplying energy to a furnace interior. Electrical energy may be supplied to the furnace interior via graphite electrodes. Following melting of the material charge, the melted material may be refined by ladle refining. Such ladle refining acts to remove impurities and homogenize the melted material. In addition, ladle refining allows for relatively tight control over the chemical and mechanical properties of the final product through improved accuracy in the composition of the final product. In addition, ladle refining allows for relatively high levels of cleanliness due to control over inclusion morphology.

**[0035]** During the ladle refining process, ladles are used to transfer melted or molten material from the electric furnace to a refining or pouring station. Ladle refining involves using ladles with a heating source to heat the melted material that is tapped from the electric furnace to a precise temperature. The ladle refining step provides an opportunity to refine the composition of the steel alloy to a desired chemical composition such that the elements are present in the ranges given above.

**[0036]** During the ladle refining step, chemicals may be added to the melted material in order to remove impurities. In addition, alloy elements may be added in order to enhance the mechanical properties of the steel alloy. In addition, the ladle refining may include a stirring action that may aid in homogenizing the temperature and composition of the melted material to achieve uniform characteristics or properties of the material. Slag may additionally be removed from the melted material in the ladle refining process.

**[0037]** The melted material is then vacuum degassed in order to remove gases. During vacuum degassing, the melted material is disposed within a degasser vacuum chamber where it is subjected to a vacuum in order to reduce or remove residual levels of

nitrogen gas in the melted material. In addition, vacuum degassing causes hydrogen to diffuse and separate from the melted material so as to prevent hydrogen-induced defects in the finished steel alloy. Both hydrogen and nitrogen gases are vented from the vacuum degasser as the steel is continuously circulated through the degasser vacuum chamber so as to improve the mechanical properties of the steel alloy.

**[0038]** Following vacuum degassing the melted material is poured into molds using an argon shield to form solid ingots. During the pouring of the melted material, argon gases are used to shield the melted material from air contamination and create a non-oxidizing environment in which the melted material may be poured into the molds. The solid ingots are later reheated for rolling into a desired shape. The material may be formed in a plate configuration from which the tool may ultimately be fabricated.

**[0039]** The material may be hot leveled after rolling in order to flatten the material while still hot. The material may be hot leveled while still on the rolling mill. The excellent flatness of the material that results from the hot leveling minimizes the amount of material that must be removed from surfaces 22 in order to produce flat and parallel ones of the surfaces 22.

**[0040]** The material may then be free air cooled on rigid, level cooling tables to below 600 degrees F prior to lifting or moving of the cooled material. The material is air cooled until complete transformation of the microstructure has occurred. The combination of hot leveling and free air cooling produces material that is naturally flat and free of waviness or wrinkles. In addition the hot leveling and air cooling eliminates the creation of residual bending stresses commonly associated with low temperature leveling and flattening operations typically applied to plate products.

[0041] Because the as-rolled and air cooled material may be slightly harder than required for the tool, the hardness may be adjusted by heat treatment or tempering. Advantageously, such tempering does not require high temperatures that otherwise result in the formation of heavy scaling on the metal surfaces. Furthermore, the tempering step also relaxes or removes residual cooling stresses that may remain in the material from the original hot rolling process. It is contemplated that the tool may be tempered to a hardness in the range of from about 277 to about 311 BHN such that the tool is suitable for use in plastic injection mold 10 tooling such as a manifold 16 for such tooling.

[0042] Referring to Fig. 1, shown is an exemplary plastic injection mold 10 having mating mold bases 12 connected to the manifold 16. As can be seen in Fig. 1, each one of the mold bases 12 includes a cavity half 14. When mated, the mold bases 12 form a mold cavity in the shape of a plastic product. In preparation for molding the plastic product, the mold bases 12 are mated and the manifold 16 is secured to mated ones of the mold bases 12. Sprues 18 and runners 20 formed in the manifold 16 allow molten plastic to be injected into the mold cavity. During the mating of the mold bases 12 and securement of the manifold 16 to mated ones of the mold bases 12 as well as during use of the plastic injection mold 10, it is essential that surfaces 22 do not become warped but remain parallel at all times. Advantageously, the above-described process for producing the tool from the steel alloy results in a tool that exhibits favorable dimensional stability such that warpage or distortion of the material is minimized, even after heavy material removal.

[0043] Referring still to Fig. 1, shown are the sprues 18 and runners 20 that may be formed into the manifold 16. Such

features may be rapidly machined into the manifold 16 due to the favorable machinability characteristics of the steel alloy. In addition, the improved ductility of the steel alloy prevents breakage around edges of such features. Furthermore, the tool steel alloy allows for repair of tooling such as the manifold 16 shown in Fig. 1. Regardless of technology, equipment and degree of care that may be exercised in machining of the manifold 16, machining errors may occur in the manifold 16 and other tooling. Such errors may require repairing. Fortunately, the excellent weldability of the steel alloy allows for weld repairs.

**[0044]** Importantly, the chemical composition and method of producing the steel alloy results in a material that is capable of meeting ultrasonic inspection acceptance criteria. Such ultrasonic inspection may be used to detect surface and subsurface flaws in the steel alloy material. Such flaws may include cracks, shrinkage, cavities, flakes, pores, delaminations, and porosity. The steel alloy as described above is substantially capable of meeting ultrasonic inspection acceptance criteria for a 5/64" flat-bottom hole.

**[0045]** The steel alloy described above also achieves improved cleanliness standards due in large part to the melting and processing practices used in making the steel alloy. For example, the addition of ladle refining, vacuum degassing and argon shield pouring enhances the cleanliness of the steel alloy as a finished product. The steel alloy material was evaluated according to American Society for Testing and Materials (ASTM) to determine the extent or severity of nonmetallic inclusion content of the steel alloy.

**[0046]** The steel alloy was evaluated according to ASTM E45, Method A microcleanliness standards and was found to have a cleanliness level equal to or better than that described below in Table II. Such inclusion may also include gas content of the

steel alloy. As shown in Table II, inclusion may be classified by chemical classification and by particle size distribution. As can be seen, the inclusions may include four types of inclusions including Types A, B, C and D respectively comprised of sulfides, alumina, silicates and globular oxides. However, as can be seen, the inclusions are limited to the extent shown in the Table II.

TABLE II

<u>Cleanliness of Steel Alloy</u>				
Type	A(Sulfides)	B(Alumina)	C(Silicates)	D(Globular Oxides)
Thin	$\frac{1}{2}$	1-1/2	$\frac{1}{2}$	1-1/2
Thick	0	$\frac{1}{2}$	0	1/2

**[0049]** Additional modifications and improvements of the present invention may also be apparent to those of ordinary skill in the art. Thus, the particular combination of parts described and illustrated herein is intended to represent only certain embodiments of the present invention, and is not intended to serve as limitations of alternative devices within the spirit and scope of the invention.